PAC Study of Cd Proton Irradiated at 77K

I. 9. PAC Study of Cd Proton Irradiated at 77K

Hanada R.

Institute for Materials Research,Tohoku University

Introduction

In several previous papers(1)-(3), the present author has reported that the PAC spectrum in Cd where the probe nuclei ^{111}In is introduced near 77 K shows the probe atom has already trapped a defect, most likely a vacancy. Since such an irradiation has been performed in a vacuum chamber with specimen clamped to a cold finger and also the vacancy migration stage (120 K) is rather close to 77 K, the beam heating during the irradiation has been suspected as the cause of the vacancy trapping during the irradiation. Namely specimen temperature goes up to 120K(the vacancy migration stage) during irradiation and so it migrates around in the lattice and eventually be trapped to ^{111}In atom giving the PAC spectrum. In order to show that this is not the case, the similar experiment as in ref.[1-3] has been performed although specimens are dipped into liquid nitrogen in the present. As shown in the resistivity study in Fe and Fe-alloys (in this volume), the specimen temperature can be kept at 77 K during irradiation by the method.

Experimental

Single crystals of 6-9 purity were irradiated by 25 MeV proton beam to introduce ^{111}In by ^{112}Cd(p, 2n)^{111}In. The specimen was kept in liquid nitrogen during the irradiation. Cares were taken that they were kept in liquid nitrogen during the transfer from the irradiation chamber to the PAC spectrum measuring cryostat. All other experimental details were the same with those in ref.[1-3]

Results

Fig.1 shows a result of PAC spectrum measurement where the crystal orientation is such that the c-axis on the detectors plane and 45 degree relative to the start detector (and so 45 relative to the 90 stop detector). Most importantly in Fig.1, the spectrum in the asirradiated state is the one with part of ^{111}In are trapped to defects. So even in the present method of irradiation of no beam heating, the ^{111}In atoms trap defects without any annealing.

A Fourier analysis of the spectrum and comparison with the quenched one reveal that part of ^{111}In trap a vacancy . This result confirms the previous report of the present author. Namely the defect trapping during the ^{111}In introduction irradiation is not due to the effect of beam heating but is a real effect, of which several possible mechanism will be discussed later.

The spectra after annealing at each temperature are also shown in Fig.1. The results show the as-irradiated state gradually develops into the substitutional site without defect trapping at 175 K and similar with those reported in ref.[2].

Discussion

Recently Metzner et al[4] have reported a result of a neutrino recoil experiment where ^{111}In atoms have already trapped vacancies even at 4.2 K in Cu when the ^{111}In probes are doped by the reaction sequence of ^{111}Sn ^{111}In ^{111}Cd. The Cu atom recoil energy becomes as high as 29 ε for the transmutation ^{111}Sn ^{111}In and sufficient to cause the displacement sequence resulting in a configuration of ^{111}In-vacancy pair.

If their model of the neutrino recoil displacement is applied to the present case of ^{111}In ^{111}Cd in Cd metal, the Cd recoil energy is estimated to be 9.8 MeV. Here the binding energy (ρ)[5] difference 0.85 MeV between ^{111}In (-88.4 MeV) and ^{111}Cd(-89.3 MeV) is used for the estimation. The estimated recoil energy 9.8eV is however slightly lower than thed Cd atom displacement energy 20 eV inferred from other metals.

So this model can not be applied to the present Cd case of vacancy trapping at 77 K. Also if this model were valid for ^{111}In in Cd, one should observe PAC signal of ^{111}In that traps a vacancy in all 77 K measurements and yet this is not the case. Namely one always observe a PAC spectrum of ^{111}In in the substitutional site without vacancy trapping if ^{111}In is doped at RT and subsequently PAC spectrum is measured at 77 K.

The other possible mechanism of the vacancy trapping to ^{111}In at 77 K would be the vacancy migration in the thermal spike caused by the atomiccollision for ^{111}In production. The thermal spike is a local high temperature region which decays quite rapidly after the atomic collision. The concept of the thermal spike was first proposed by Brinkman[6] and computer simulated by Vineyard[7]. Recently de la Rubia et al[8] have reexamind it using a high speed computer where they have found the thermal spike size is about 30 A in diameter and lasts about 5ps in Cu for 5 KeV initial Cu recoil energy. Also they have found the crystal is locally melted in the thermal spike, which is inferred from the simulated atomic correlation function that is quite similar with that of the liquid determined by experiments. Their model of the local melting may be applied to interprete the present vacancy trapping as follows. The diffusion coeffcient of an atom in liquid state is the order of 10 - 4 cm^2/s. Therefore, the diffusion distance of an atom in the thermal spike is the order of tD =1-10 A, which is comparable with the daiameter of the spike. Also the computer simulation reveals

that vacancies are present in the spike such an amount as to reduce the density by 10-20 % for several ps. So the probability of ^{111}In atom that is at the center of the thermal spike meets with a vacancy or vacancy aggregates should be quite high resulting in the pair formation. This interpretation remains speculation until the perturbedangular distribution (PAD) technique is improved as to resolve the phenomena within several ps after the nuclear reaction. At present the time window of the technique is limited to several ns after the reaction.

Acknowledgement

The present author would like to thank to the staff of the CYRIC Cyclotron for their machine operation and the beam transport. Also he would like to thank to Prof.G.L.Zhang (Institute for Nuclear research, Shanghai) for his useful comments during his visit to IMR. The author also would like to thank to the staff of IMR machine shop for their making the irradiation cryostat.

References

1) Hanada R., CYRIC Annual report **40** (1986) 1985.
2) Hanada R., Materials Science Forum **15/18**(1987) 1129.
3) Hanada R., J. Nucl. Materials **169** (1989) 9.
4) Metzner H., Sielmann R., Klaumunzer S. and Hunger H., Phys.Rev. B **36** (1987) 9535.
5) Table of Isotopes,7th edition
6) Brinkman J. A., J.A.P. **25** (1954) 961.
7) Vineyard G.H., in Radiation Effects in Inorganic Solid, Discussion of Faraday Soc. **31** (1961) 7.
8) Diaz T. de la Rubia, Averback R. S., Benedek R. and King W. E., Phys. Rev. Lett. **59** (1987)1930.

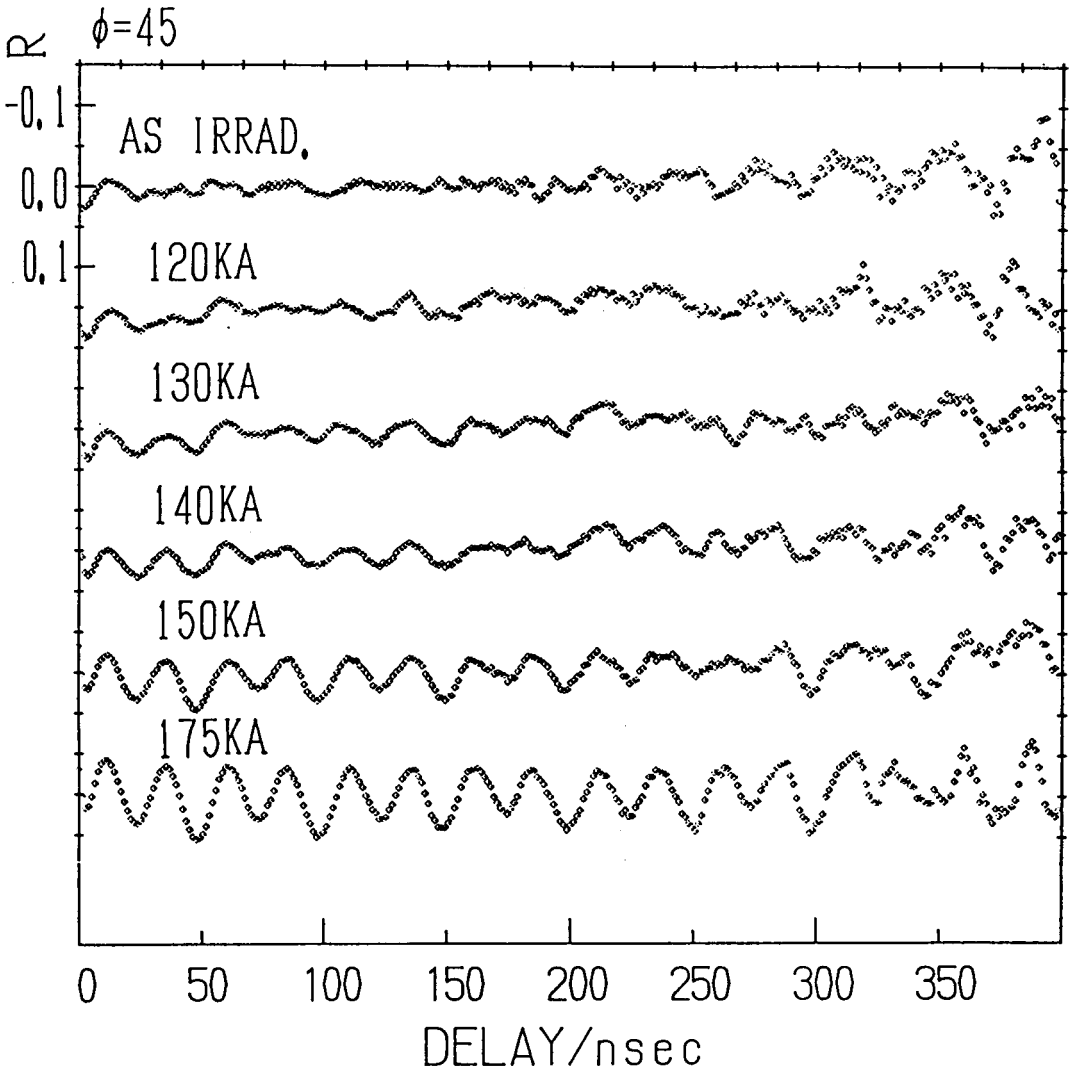

Fig. 1. PAC spectrum of ^{111}In in 77K irradiated pure Cd.Top: as-irradiated. 120KA-175 KA: Annealed for 10min.at each temperature. Measurement: at 77 K.